How to make the charging infrastructure for electric vehicles smart

Whitepaper
11-2022

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1 Abstract

Renewable energies and the increasing emergence of electric vehicles are putting a strain on the electricity grid. The former are not constantly available, and the latter require additional energy while charging. This leads to the need for introducing a new, smart charging infrastructure to avoid instabilities at the grid level. This white paper explains what is involved in making a charging infrastructure truly "smart" and what obstacles can be expected along the way. It also outlines why vehicle owners do not need to fear batteries degradation, and which semiconductor devices and other supporting technologies Infineon provides for such applications.

2 Introduction

Wind and solar energy are sustainable, but the amount of energy they produce is hard to predict. It can depend on the weather, time of day, and the season. Complicating matters further, consumption does not necessarily align with generation. This makes the temporary storage of excess energy and feeding it back into the grid when needed a necessity. In addition, these electricity storage devices should be able to contribute to a controlled and active stabilization of the grid.

Electric Vehicles (EVs), and to a limited extent Plug-in Hybrid Electric Vehicles (PHEVs), can act as a distributed Energy Storage System (ESS). And because of the large storage capacity of their batteries, they can support such a stabilization in several ways. This, however, requires a standardized, secure, and intelligent supply environment for the energy transfer from the grid to the vehicle (G2V) and from the vehicle to the grid (V2G). In addition, a bidirectional information exchange with a smart Energy Management System (EMS) over standardized protocols is a must.

A lack of regulations and standards for business processes reduces the momentum to transit the traditional grid to a smart, green power grid. The missed standards for smart buildings and a lack of digital intelligence at the Distribution System Operator (DSO) lead to a lot of the storage capacities of the EVs being untapped. Contributing to that are the rudimentary available financial stimuli for potential stakeholders and investors. What is available are mostly isolated solutions from different players, for example, for cloud and subscription-based services. But these lead to an undesirable fragmentation of the market. Only a standardized and regulated approach will enable attractive business models for system operators and car owners to build or take part in a Smart Charging Infrastructure (SCI) for electric cars.

3 Does a time-shifting capability already imply a smart charging infrastructure?

Smart charging is more than just shifting the charging time of any electrical vehicle (xEVs) to the time of the lowest grid load. An SCI can also support grid stability in several ways because of the enormous storage capabilities of xEVs. Examples would be a bidirectional load stabilization or a voltage and frequency compensation.

There are other possibilities as well: xEVs can act as electricity or energy suppliers for households (vehicle to home/V2H) or businesses (vehicle to business/V2B). V2G, V2H and V2B have the potential to create new commercial opportunities for grid operators and car owners. But only if implemented properly.

V2H and V2B contrast with V2G in that energy is fed back into private networks, rather than public ones. This means that different requirements apply and that they do not have to comply with grid connection standards.

So, an SCI does not only consist of the xEV, the charging station, and the grid, it also connects with other Energy Storage Systems (ESS), homes, buildings, and office spaces. And beyond that, it communicates with payment systems, fleet management, brokers, and the Internet of Things.

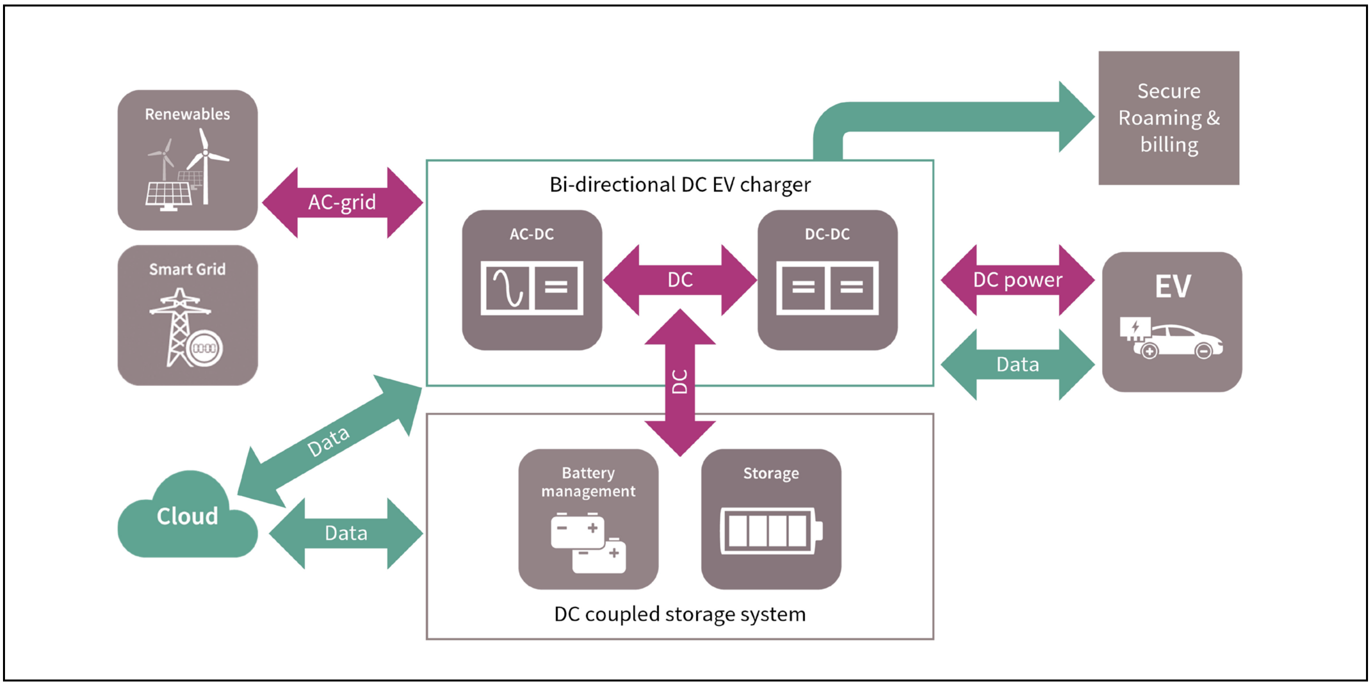

Figure 1 A simplified diagram of a smart charging infrastructure

Such an SCI demands investments in hard- and software on the vehicle side, the operator side, and with various other providers. The capital invested needs to be protected by regulations and standards for the power and communication interfaces.

4 Where can V2G with smart charging help?

The amount of greenhouse gas emissions needs to be reduced dramatically worldwide, and the transportation sector is a large contributor to them. To achieve the climate goals of the Paris Agreement, at least 35% of all road vehicles sold by 2030 should be driven electrically. But the reduction of our carbon footprint can only happen if the energy used comes from sustainable energy sources. These sources, together with other distributed energy resources, pose a burden on network operators. Their problem is that it is hard to predict when and where a certain amount of electrical energy will be generated, and when it will be consumed. In addition, the increasing number of xEVs may affect the dynamics of the power distribution systems and their performance, by, for example, overloading transformers or cables.

A smart charging infrastructure can support Distribution System Operators (DSOs) and Transmission System Operators (TSOs) to achieve their goal of a reliable and stable grid, even when using dynamic energy sources. Vehicle owners may also benefit from new business models if they allow the operators to use energy from their car's batteries as Distributed Energy Resources (DER). These models could include, but are not limited to, energy broking while the car is parked or utilizing the battery's stored energy for grid stabilization.

For operators, vehicles and charging stations that are capable of transferring energy to and from the grid could assist in demand response and balancing the grid. This is achieved by buffering and storing energy during periods of high availability or low demand and feeding it back to the grid during phases of high demand or low availability, thus reducing the waste of energy from sustainable sources.

Further services are possible as well. These include the provision of a base load energy over a few hours, draining the batteries only marginally (about 10%), peak shaping, or acting as a spinning reserve. Furthermore, active regulation regarding voltage and frequency is feasible within certain limits, as are power quality services like reactive power regulation, low voltage ride-through, or transient reduction from photovoltaic sources. Electric Vehicle Supply Equipment (EVSE) could also act as shunt active filter to reduce harmonics.

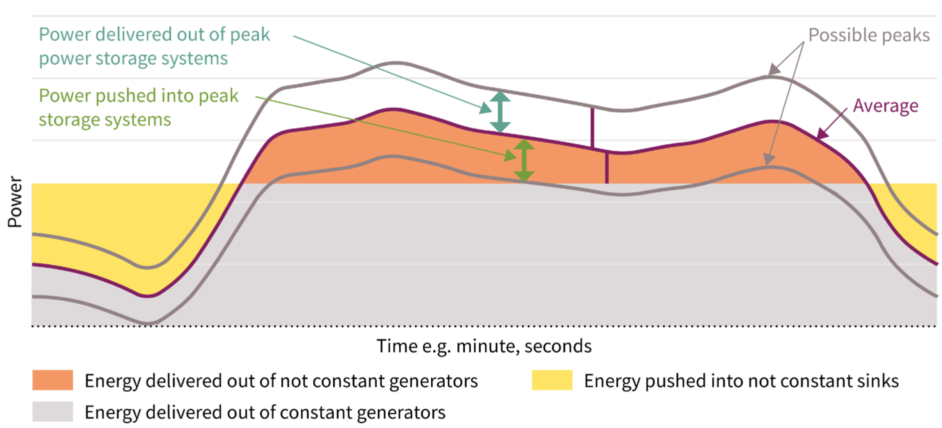

Figure 2 Allocation of energy between the individual sources and energy storage system

But not every possible use case is practical in reality. How quickly a source can provide how much energy must always be considered. xEVs are only reliable in delivering a certain, limited amount of energy, but are unreliable as a power source. This is because operators have no way of knowing how many cars are available at any given time and what capacity they have available. Operators must respect their supply contracts, so the quantity of energy they withdraw must be predictable. xEVs can supply energy quickly, but only for a few hours. This means that peak shaving cannot be based on xEVs. Here, stationary and permanently grid-connected peak-load power plants, or other DSO-owned large and medium size systems, are indispensable. The same applies to the median required apparent energy, where large and medium scale power plants acting as constant energy sources are also necessary.

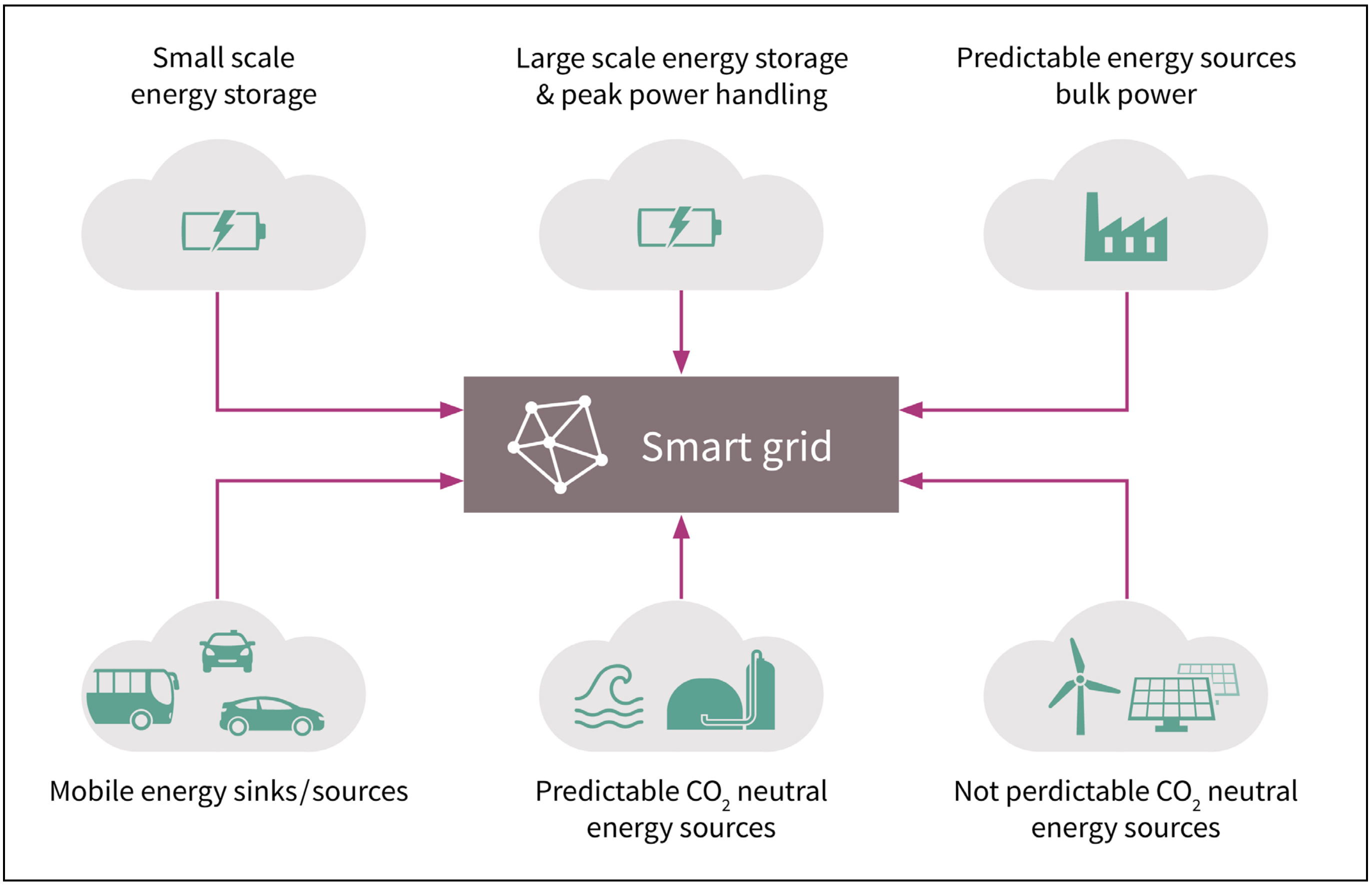

Figure 3 Various energy sources and their availability

xEVs, like all other non-constant energy sources, can only deliver the energy difference between the constant sources and the apparent energy demand on a medium timeframe, ranging from tens of minutes to a few hours. They cannot cover fast transients.

5 What makes a charging infrastructure smart

The extra burden put on the distribution grid by the increasing number of xEVs requires an adaptation of the infrastructure to cope with the projected load. Making the charging infrastructure truly smart necessitates bidirectional power transmission, and thus distribution facilities that ensure power can flow in both directions: to and from the vehicle. Current grids do not necessarily support this bidirectionality, especially at the DSO level.

An optimal control of energy transfer for V2G and G2V is crucial, and this calls for additional investments beyond the power grid: in a reliable infrastructure for two-way communication and in the security of those networks and communication systems. This keeps personal information, billing data, and the communication with a Public Key Infrastructure (PKI) for mutual authentication of all stakeholders secure.

But it goes beyond these facets: Being highly interconnected, an SCI has the potential of putting utilities, charging stations and their operators, as well as vehicles at risk, endangering grid and properties. This means that a smart charging infrastructure must take care of all aspects of cybersecurity. It is, for example, important that individual parts of the system have no direct connection with each other. Only data sets should be exchanged, and trusted and protected IP should be isolated. This prevents not only, for example, a DSO, from gaining direct access to the heating system of a building, but also the propagation of attacks.

The equipment needs not only to communicate with the xEV but also with electricity providers, payment operators, an energy management system, and a PKI system. It could also even interchange information (and energy) with the home of the vehicle owner and possibly with the premises of employers or shops. Standards for these information transfers are indispensable to prevent an uncontrolled proliferation of proprietary solutions.

Presently, three different protocols are being discussed: The OpenADR (Open Auto Demand Response) standard, managed by the OpenADR Alliance, will exchange data at the grid level, provide communication between charging stations and energy providers, DSOs, and brokers, and send data from buildings to the grid. Within buildings, the EEBUS standard, developed and maintained by the EEBUS Initiative, will be used for energy management, reading the provider’s energy pricing information, as well as other data sets. Matter, provided by the Connectivity Standards Alliance (CSA), will communicate with Internet of Things (IoT) sensors and control entities. All are IP-based protocols but use different OSI (Open Systems Interconnection) layers. TCP/IP can be employed for the exchange with various cloud systems, for example, for fleet management, payments, and invoice and accounting systems.

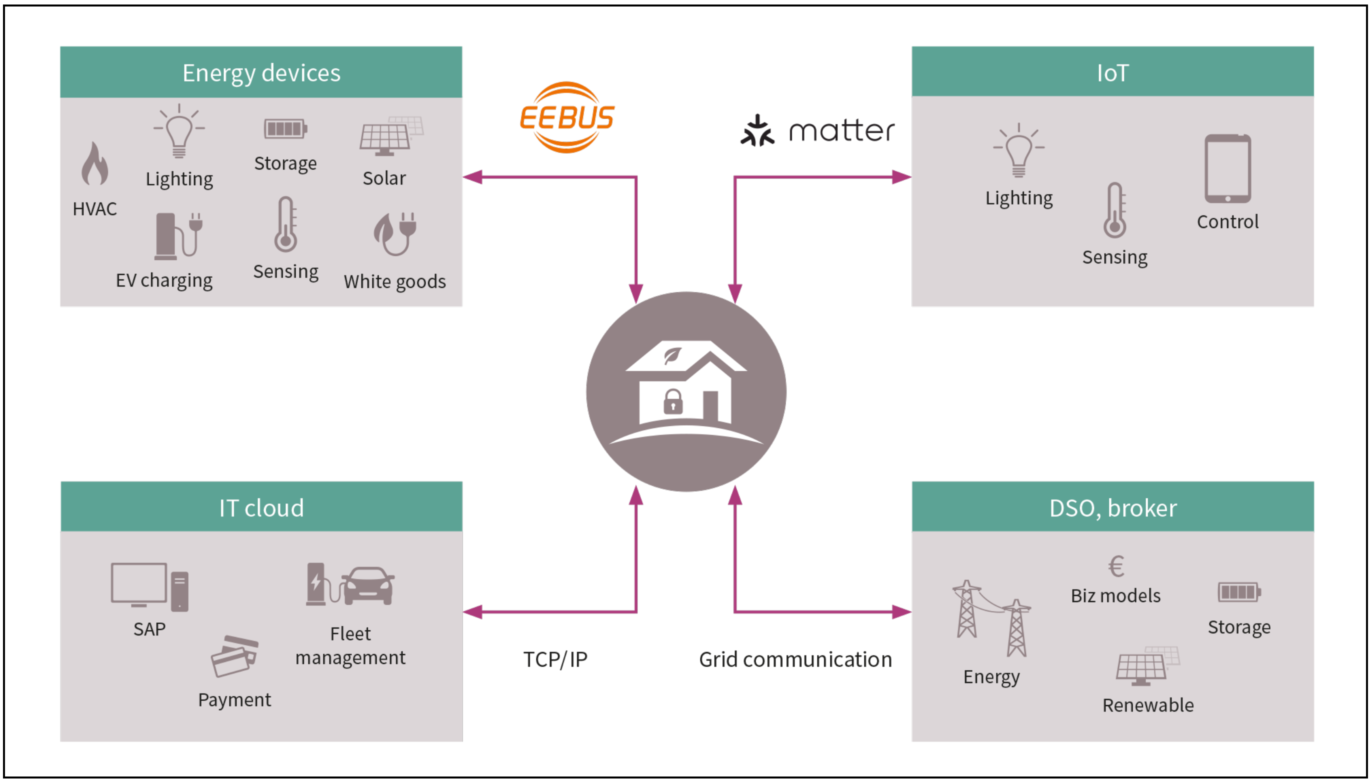

Figure 4 Example for a smart charging ecosystem and load management

6 The unfounded fear of battery degradation

A special challenge is the fear of vehicle owners of a presumed battery degradation through additional charge/discharge cycles or high currents. Battery degradation depends on several factors: One is the amount of energy drawn and the rate at which it is drawn. In this case, the degradation is a function of the Depth of Discharge (DOD) and the cycling frequency. Other factors are the chemical structure of the battery and its manufacturing process. To minimize degradation, an SCI should take care of the needs of the battery. It should keep the charge/discharge rate (C-rate) at a value of 0.5 or below. The same is true for the DOD, where the energy management system should target an average discharge of about 10%, with a maximum discharge of 30% to retain the mobility of the vehicle. If all of this is considered, the battery will not exhibit a reliability problem.

Other consumer requirements must be respected as well. Depending on their preferences, they expect either a target energy in their battery when they want to use their vehicle (e.g., 80% for returning from work and running errands on the way) or a 100% charge at a certain time (e.g., when going on holiday). And they demand economic benefits, which compensate for having their car’s battery used for peak shaving, grid balancing, or energy delivery. A smart charging infrastructure allows vehicle owners to set these choices through an interface to the EMS.

Yet, all this means high-cost investments into the charging and grid infrastructure. And standards and regulations for all these are up until now nonexistent.

7 What is Infineon's offer for an SCI?

A smart, secure, and intelligent bidirectional electrical vehicle supply environment requires not only chargers but also a complete ecosystem. Infineon is the leading semiconductor provider in xEV charging because of its comprehensive product portfolio and broad system knowledge. This includes not only the power stage but also system control, connectivity, security, sensors, and embedded processing. Yet Infineon's application expertise and portfolio offer flexibility far beyond just the charger – it extends to the smart charging infrastructure.

In the power stage, Infineon's wide bandgap technologies like CoolSiC™ silicon carbide (SiC) MOSFETs and diodes, as well as CoolGaN™ gallium nitride (GaN) transistors, allow engineers to reduce the power losses in the electric vehicle supply equipment through the inherently higher efficiency of the wide-bandgap (WBG) devices. With them, they can also create systems which permit modular approaches to further drive losses down. Additional power devices, like TRENCHSTOP™ IGBTs and EiceDRIVER™ gate driver ICs complete the power stage ecosystem.

If higher security levels are needed for system control or embedded edge computing, the AURIX™ family based on Infineon's 32-bit TriCore™ architecture is a good choice. It has an embedded Hardware Security Module (HSM) with a separate logical protection domain. AURIX™ devices are well suited for applications which have specific security requirements. Extensive software packages support the processors of this group.

Tamper-resistant security devices based on the latest cryptography, such as Infineon's OPTIGA™ family, simplify the implementation of the security needs of an SCI. OPTIGA™ TPM trusted platform module security controllers can be used in communication gateways or for edge computing within the charging station.

Beyond that, Infineon also has a broad range of offerings for bidirectional connectivity, for example, the AIROC™ wireless solutions for Wi-Fi and Bluetooth®. Sensors like the XENSIV™ series allow current measurements, and Flash memory and RAM products are available as well.

System control	Power stage	Technologies	Connectivity	Sensors	Security	External memory
› XMC™ 4000 MCU › PSoC™ 6 › AURIX™	› Easy power modules › IGBT discretes › EiceDRIVER™ gate drivers for SiC MOSFETs, & IGBTs with various safety features	› CoolSiC™ › TRENCHSTOP™ IGBT7 › CoolMOS™ › CoolGaN™	› Wi-Fi and BTBLE solutions CYW***	› Current sensors integrated shunts & XENSIV™ TLI4971/2-A120T5-E0001	› OPTIGA™ embedded security solutions › Secured communication/ secured host firmware update OPTIGA™ Trust M	› Flash and RAM solutions

Figure 5 Infineon offers a broad range of devices and technologies to support the implementation of a smart charging infrastructure for electric vehicles

Reference designs are the key enabler for the customer in EV charging application domain. The solutions can accelerate design study, software development and enable flexibility and cost saving in the R&D process at the customer. Infineon offers the complete reference design portfolio focusing on 3 main charger types in the DC EV Charging application:

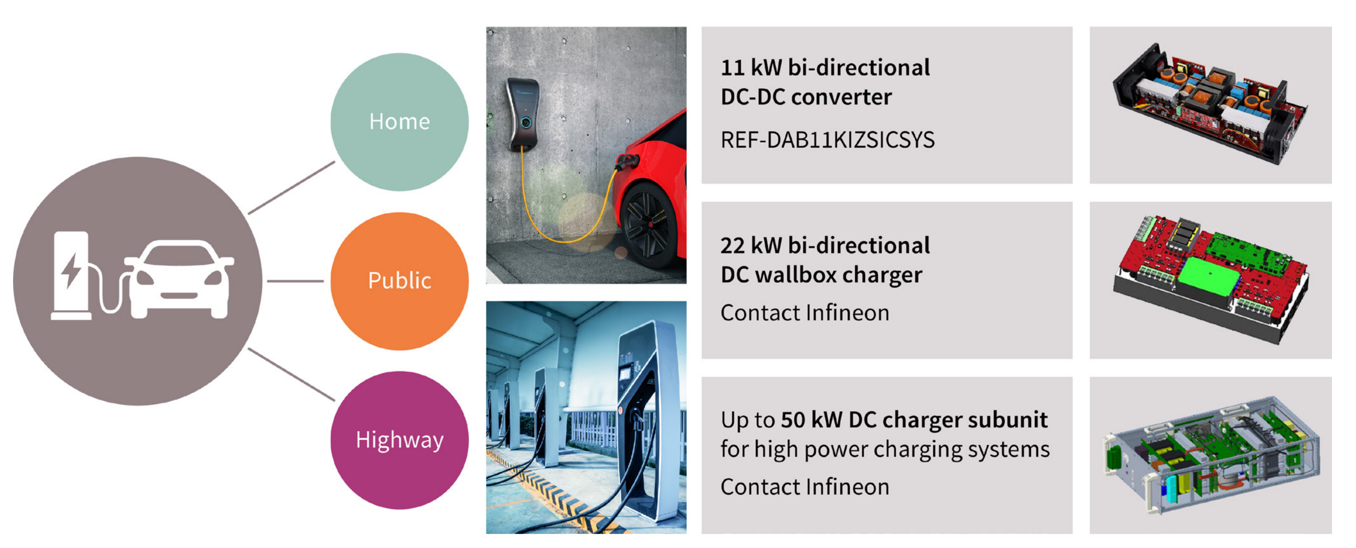

Figure 6 3 main charger types in the DC EV Charging application

An example is the available REF-DAB11KIZSICSYS, which is an 11 kW SiC bi-directional DC-DC converter board for EV charging and other ESS applications, using 1200 V and 1700 V CoolSiC™ MOSFETs. It comes with a complete set of design files, enabling engineers to realize their own development based on a proven hardware.

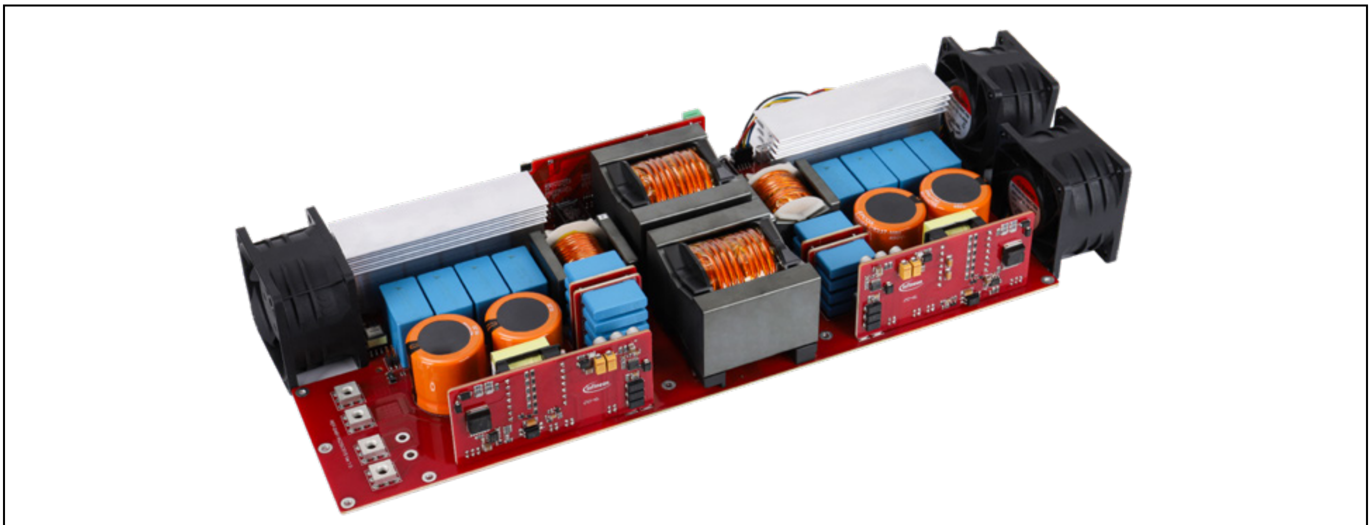

Figure 7 The REF-DAB11KIZSICSYS bi-directional DC-DC converter board

The next reference designs are already in the pipeline, higher power levels, software support and higher level of integration will provide further support to our customer and accelerate their time to market for future projects.

8 Conclusion

Because of the increased use of renewable energies and the predicted exponential growth of xEVs, the power grid needs to be supplemented with a smart charging infrastructure to ensure its stability. In this regard, it is not sufficient to simply shift the charging time to a time of low grid load. Rather, a smart system can also use the xEVs connected to an EVSE to improve the performance of the grid by contributing to efficiency, stability, and reliability in a variety of ways.

However, this will require new standards and regulatory intervention to prevent proliferation, something that has only been rudimentarily implemented to date. In particular, more work is needed in the area of communications and security, for example in the protocols to be used and cybersecurity. In addition, it still has to be assessed which measures make sense, or which measures a xEV can contribute to at all. And lastly, vehicle owners need to be convinced that allowing their vehicle to be part of a smart infrastructure does not degrade their battery and might even offer monetary benefits.

Infineon supports the introduction of a smart charging infrastructure with a broad portfolio of high-performance semiconductor components and in-depth application knowledge.

9 List of abbreviations

- C-Rate: Charge/Discharge Rate
- CSA: Connectivity Standards Alliance
- DER: Distributed Energy Resource
- DOD: Depth of Discharge
- DSO: Distribution System Operator
- EEBUS:
- EMS: Energy Management System
- ESS: Energy Storage System
- EV: Electrical Vehicle
- EVSE: Electric Vehicle Supply Equipment
- G2V: Grid to Vehicle
- HSM: Hardware Security Module
- OpenADR: Open Auto Demand Response
- PHEV: Plug-in Hybrid Electrical Vehicle
- PKI: Public Key Infrastructure
- SCI: Smart Charging Infrastructure
- SOC: State of Charge
- TSO: Transmission System Operator
- V2B: Vehicle to Business
- V2G: Vehicle to Grid
- V2H: Vehicle to Home
- V2L: Vehicle to Load
- xEV: Any Electrical Vehicle

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Published by
Infineon Technologies AG
Am Campeon 1-15, 85579 Neubiberg
Germany

Date: 11 / 2022